AGES OF LUNAR MARE BASALTS IN MARE FRIGORIS AND OTHER NEARSIDE MARIA

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Introduction: Lunar mare basalts cover about 17% of the lunar surface [1], occur preferentially on the lunar nearside, and often fill the low-lying inner depressions of large impact basins and craters such as Imbrium or Orientale. Basalts in Mare Frigoris are special in that they occur in an area that is not clearly related to any unambiguously accepted impact structure. Mare Frigoris may be part of the large and very old Procellarum basin, but the existence of this basin is still disputed [e.g., 2, 3]. Wilhelms [3] found the basalts of eastern Mare Frigoris to be of Imbrian age and the basalts of central and western Frigoris (west of ~10˚E) to be younger and of Eratosthenian age. He suggested that the concentration of Eratosthenian and Imbrian eruptions in Mare Frigoris, Mare Imbrium and Oceanus Procellarum is due to a thin lithosphere beneath the putative Procellarum basin. The majority of mare basalts in Mare Frigoris is characterized by relatively homogeneous low titanium abundances, bright albedo, strong 1 µm- and prominent 2 µm-absorption bands [4, 5]. Based on the morphology of pre-mare craters, the thickness of the basalts in Mare Frigoris has been estimated to be less than 500 m [6, 7]. Whitford-Stark [8] proposed that the basalts in Mare Frigoris were emplaced by flood-style eruptions 3.2-3.6 b.y. ago. Based on Lunar Orbiter IV images we performed new crater size frequency distribution measurements in order to determine surface model ages of basalts exposed within Mare Frigoris. In addition, we are expanding our crater counts to several other lunar areas, which are covered with mare basalts, such as Mare Nectaris, Mare Smythii, Mare Marginis, Mare Vaporum, Sinus Medii, and Palus Putredinis. We also determined ages for basalts exposed in craters Schickard, Grimaldi, Crüger, Hubble, Joliot, Goddard, and two lava ponds south of the crater Endymion.

Technique: We have previously described our approach to derive model ages of lunar mare basalts with crater size-frequency distribution measurements in detail [e.g., 9, 10, 11]. For this study we followed the same procedure of defining spectrally homogeneous areas on a high-resolution Clementine color ratio composite and to perform the crater counts on Lunar Orbiter images. The definition of homogeneous units is one of the crucial prerequisites for reliable age determinations with crater size-frequency distribution measurements. For each of our spectrally homogeneous units we assume that they were formed within a short period of time with, to a first order, homogeneous major mineralogy, such as a single eruptive phase.

Results: We performed crater counts for 37 spectrally homogeneous basalt units within Mare Frigoris. Our data indicate that surface ages of Frigoris mare basalts range from 2.61 to 3.77 b.y. (Fig. 1). Most units were formed in the Late Imbrian Period between 3.4 and 3.8 b.y. This is consistent with observations made for other lunar nearside basalts in Oceanus Procellarum, Imbrium, Serenitatis, Tranquillitatis, Cognitum, Nubium, Insularum, Humorum, Humboldtianum, and Australe [9, 10, 11].

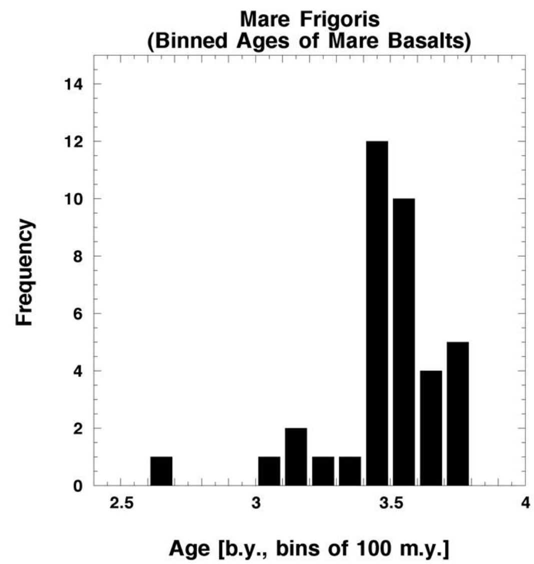

Fig. 1: Distribution of basalt ages in Mare Frigoris

Based on our crater counts we observed Eratosthenian ages only for four units with the youngest (2.61 b.y.) having relatively large errors of +0.5/-0.34 b.y. Three of these units are located in the central parts of Mare Frigoris north of crater Plato, and one Eratosthenian unit is located close to the eastern edge of Mare Frigoris northwest of crater Baily. This concentrated distribution of Eratosthenian basalts north of Plato is consistent with the map of Wilhelms [3]. However, all our Eratosthenian units are relatively small in size and while located in the general area mapped by Wilhelms [3], are not connected to each other. The geologic map of Wilhelms and McCauley [12] does not show Eratosthenian basalts in the area north of Plato. In the geologic map of Lucchitta [13] most of the basalts in Mare Frigoris are of Imbrian age (Im) with only a small area southwest of the crater Fontenelle and a larger area around the crater Harpalus being Eratosthenian in age. Our new crater counts confirm Imbrian ages for most of the Frigoris basalts and we also observe Imbrian ages for areas that were mapped as Eratosthenian in age by Lucchitta [13].

If we look at the spatial distribution of basalt ages in Mare Frigoris, it appears that older basalts (3.5-3.8 b.y) occur east of 0˚ longitude and younger basalts (3.4-3.6 b.y.) are exposed between 0˚ and 40˚W. We also found evidence that basalts west of 40˚W are older (3.3.5-3.8 b.y.) and similar in age to the eastern basalts of Mare Frigoris.

We are currently expanding our crater counts to several areas so far undated in our study. These areas include Mare Nectaris, Mare Smythii, Mare Marginis, Mare Vaporum, Sinus Medii, Palus Putredinis, and the craters Schickard, Grimaldi, Crüger, Hubble, Joliot, Goddard, and two lava ponds south of crater Endymion.

According to the geologic maps of Stuart-Alexander and Tabor [14] and Elston [15], the Nectaris basin is filled with Imbrian basalts and at the southeastern edge, southwest of crater Bohnenberger, with Eratosthenian dark mantle deposits. Our preliminary crater counts also indicate Imbrian ages for the Nectaris basalts but we do not observe Eratosthenian ages for the dark mantle deposits. As for numerous other areas covered with dark mantle deposits, we derived an Imbrian age for these pyroclastics.

Preliminary results indicate that basalts in Mare Smythii are significantly younger than basalts in Mare Marginis and that they might be of Eratosthenian age. For Mare Marginis basalts we found Late Imbrian ages. The geologic map of Wilhelms and El-Baz [16] indicates that both mare areas are of Imbrian age, hence being inconsistent with our new data. This map also shows that the basalt fill of crater Goddard is of Imbrian age and this could be verified with our crater counts. Craters Hubble and Joliot are filled with Imbrian basalts in the geologic map [16] and crater counts also suggest an Imbrian age of these basalts.

The geologic map of Wilhelms [17] shows two distinctive basalt types in Mare Vaporum, which are part of the Imbrian-age Procellarum Group. In addition, several dark mantle deposits have been mapped, which were thought to be of Eratosthenian age. In the past dark mantle units have been problematic in terms of estimating their ages because of their unusual albedo obscuring craters, the physical properties of the mantle and crater degradation, or both. According to our preliminary crater counts none of the dark mantle units is Eratosthenian in age but all are of Imbrian age and often older than adjacent mare basalts. This is consistent with observations of Weitz and Head [18]. The map of Wilhelms and McCauley [12] shows Imbrian ages of all basalts in Mare Vaporum. For these basalts we determined Imbrian ages, which are consistent with previous geologic maps.

The geologic map of Wilhelms [17] also covers parts of Sinus Medii and indicates two different Imbrian basalts in this area and Eratosthenian dark mantle deposits. Our crater counts confirm Imbrian ages for these basalts. According to our preliminary age determinations, light plains (Cayley Formation) in this region are of Late Imbrian age and are younger than the Orientale event. Köhler et al. [19] made similar observations for northern-nearside light plains. Imbrian ages of the basalts and light plains in Sinus Medii are consistent with the map of Wilhelms and McCauley [12].

The Palus Putredinis area has been mapped for example by Hackman [20], Swann et al. [21], and Howard and Head [22]. In the map of [20] the basalts are of Imbrian age and this is consistent with new ages derived from crater size-frequency distribution measurements. For Palus Putredinis we determined basalt ages that are close to be Eratosthenian and basalt samples returned from the Apollo 15 mission indicate ages from 3.20 to 3.4 b.y. [e.g., 23, 24].

The floor of the crater Schickard exhibits a bright central part and two darker parts in the northwest and southeast. Karlstrom [25] mapped the bright part as Imbrian in age and the dark parts to be Eratosthenian in age. We performed crater counts only for the dark parts and found Imbrian ages for both areas. This is inconsistent with the geologic map of Karlstrom [25] but is consistent with crater counts of Greeley et al. [26].

Mare basalts exposed within Grimaldi were mapped as Eratosthenian by Wilhelms and McCauley [12] and McCauley [27]. This is consistent with our new crater counts and with crater counts of Greeley et al. [26].

Lava ponds in the craters Crüger, Rocca A and between these two craters are of Imbrian and/or Eratosthenian age (EIm) in the geologic map of Scott et al. [28] but our data show evidence only for an Imbrian age of these basalts.

Lava ponds south of the crater Endymion were mapped by Lucchitta [13] as Imbrian in age. Based on our new crater counts we determined a Late Imbrian age of ~3.6-3.7 b.y. for these basalts.

Conclusions: From our crater counts we conclude that (1) Mare Frigoris is mostly filled with Imbrian basalts but there are a few areas that are covered with Eratosthenian basalts, (2) these Eratosthenian basalts occur in several small-sized areas north of the crater Plato but are not connected with each other as shown by Wilhelms [3], (3) basalts in Mare Nectaris, Mare Vaporum, Sinus Medii and Palus Putredinis are Imbrian in age, (4) basalts in Mare Smythii are younger than in Mare Marginis, contrary to the geologic map of Wilhelms and El-Baz [16], (5) basaltic fills of the craters Goddard, Hubble, and Joliot are of Imbrian age, (6) there are no Eratosthenian basalts in the crater Schickard but basalts in the crater Grimaldi are Eratosthenian in age as mapped by McCauley [27], (7) lava ponds in the craters Crüger, Rocca A and between these two craters were formed during the Imbrian Period, (8) lava ponds south of the crater Endymion are of Late Imbrian age, (9) none of the areas mapped as Eratosthenian dark mantle deposits is Eratosthenian but all are Imbrian in age and often older than adjacent mare basalts.

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